Identification of Ground Motion Parameters that Control Structural Damage using a Slepian Process Model

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Non-Technical Summary

A better understanding of which ground motion parameters contribute significantly to structural damage is critical to providing engineers with the information they need to develop safe design guidelines and maximize occupant safety. This project, which is currently underway, seeks to identify these parameters using a statistical model called a Slepian process model. A Slepian process model assumes that the large values of a process follow the basic pattern of the entire process but allow for some level of variability in order to predict the behavior around and above these large values.

Annual Project Summary

The project began May 15, 2002. The following project summary reports on the work conducted between May, 2002 and October 1, 2002.

Introduction and Background

The analyses of random processes for design purposes can be viewed in terms of predicting the behavior of the process above a threshold level, within a specified threshold band, or after a maximum. Slepian (1961, 1962) developed a normalized covariance formulation to study a random zero-mean process above a specified threshold that lead to the following model

$$x_{uz}(t) = uA(t) + zB(t) + \Delta t \tag{1}$$

where,

$$A(t) = \frac{R_{xx}(t)}{\lambda_0} = \frac{R_{xx}(t)}{\sigma_x^2} \tag{2}$$

$$B(t) = -\frac{R_{xx}'(t)}{\lambda_2} = -\frac{R_{xx}'(t)}{\sigma_{x'}^2} \tag{3}$$

where $R_{xx}(t)$ and $R_{xx'}(t)$ are the covariance function and its' derivative, respectively, λ_o and λ_2 are the zeroth and second spectral moments; σ_x^2 is the variance of the process; and $\sigma_{x'}^2$ is the variance of the process derivative. The covariance function can be expressed as

$$R_{xx}(t) = E[x(t+s)x(s)] \tag{4}$$

In the first term on the right-hand side of equation (1), the variable u is the threshold level specified by the analyst. In the second term, the variable z is the value of the derivative of the process at crossing. The last term in equation (1), $\Delta(t)$, is the catch all for any non-stationary, non-Gaussian behavior and is generally neglected when applying the model. This is however a very important term when studying the dynamic behavior of complex dynamic systems. Interestingly, as can be seen upon inspection of equation (1), once the nature of the covariance function is established it is possible to obtain predictions for various crossing levels by simply varying the threshold level without tedious computation. Expected value and regressive forms of equation (1) can also be used to develop predictive models and will be used in this study.

Summary to Date

One current constraint on the expected value form of the Slepian Type I model is the assumption of Gaussianity of the parent process ensuring Rayleigh distributed peaks (Cartwright and Longuet-Higgins 1956). This results in the expected value form of equation (1)

$$E[X_{uz}(t)] = \frac{R_{xx}(t)}{\sigma_x^2} - \sqrt{\frac{\pi}{2}}\sigma_{x'} \frac{R_{xx}'(t)}{\sigma_{x'}^2} \tag{5}$$

However, for highly nonstationary non-Gaussian ground motion this is definitely not the case. Figure 1 shows that the ***strong ground motion portion*** of the records for six earthquakes from different parts of the world, i.e. Taiwan (1999 Chi Chi), United States (1940 El Centro), and Japan (1995 Kobe), are very close to following a normal distribution, i.e. Gaussian, whereas the entire record is clearly non-Gaussian. This conclusion is reinforced by examining the kurtosis for each case presented in Figure 1. recall that a kurtosis of 3.0 is somewhat indicative of a normal distribution, i.e. Gaussianity, whereas a high kurtosis indicates non-Gaussianity.

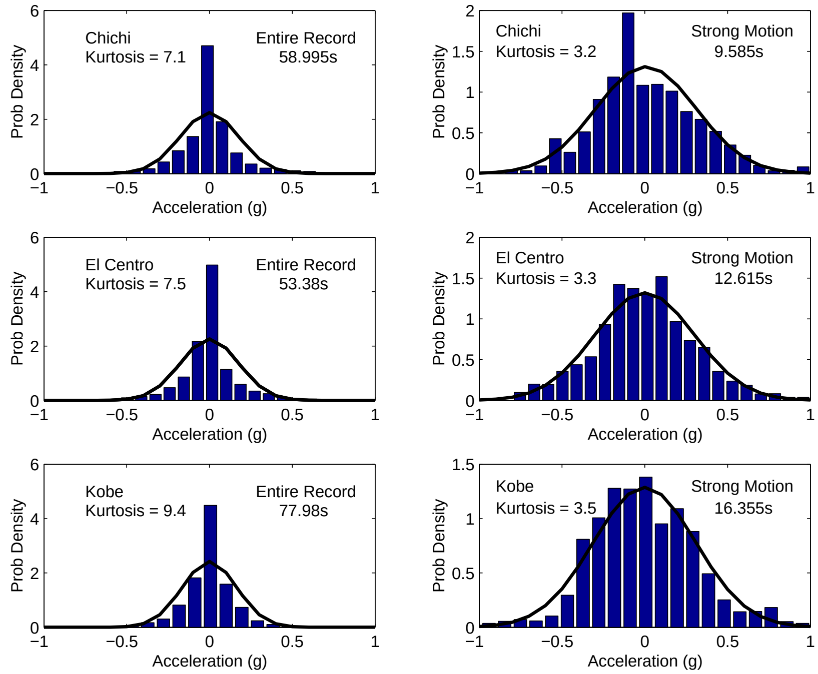

FIGURE 2: Comparison of the Gaussianity for the strong motion duration of an earthquake record with the entire record.

In the present study, the strong motion duration (Vanmarcke and Lai 1980), s_o, of a record was taken to be

$$s_o = \begin{cases} \left[2\ln\left(2s_o/T_o\right)\right]\left(I_o/a_{\max}^2\right) & s_o \geq 1.36T_o \\ 2I_o/a_{\max}^2 & s_o \leq 1.36T_o \end{cases} \tag{6}$$

where T_o is the total length of the ground motion record, I_o is the Arias intensity, and $a_{\max}$ is the absolute maximum acceleration in the record. It follows that the peaks of each record are Rayleigh distributed and the Slepian Type I model provides a good prediction of the expected value of the behavior above various threshold levels. As expected, the same is true for highly nonlinear oscillators excited by the strong motion portion of the record given in equation (6), as shown in Figure 2.

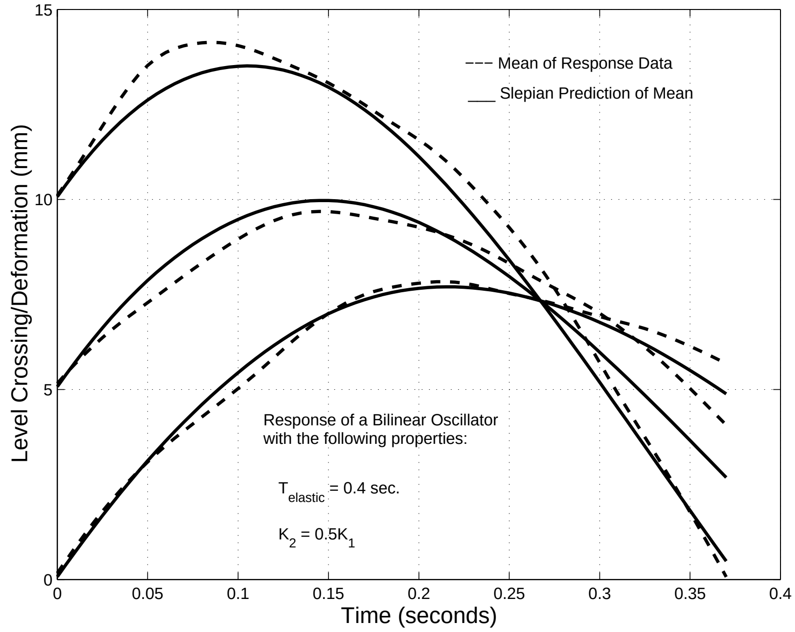

FIGURE 2: Slepian prediction above various level crossings for a bilinear oscillator excited by the 1940 El Centro earthquake.

Work Remaining

Correlation of the damage predicted by the Slepian model, based on the expected value of the behavior above a level crossing, will be pursued. This will involve a range of structural models including an elasto-plastic oscillator, several bilinear oscillators, MDOF shear building models, and a MDOF IDARC reinforced concrete model. The benchmark for damage prediction and correlations will be the well-known Park-Ang damage model (Park and Ang 1985; Park et al. 1985).

Preliminary Results

- The Slepian Type I model predicts extreme behavior for ground acceleration, i.e. the expected value form, very well regardless of the characteristics of the record.

- Extreme behavior of highly nonlinear oscillators, which is directly related to permanent damage of structural systems, is predicted even better than the ground acceleration. This is primarily due to a dominant period in the response making the power spectral density of the response very narrow banded.

Reports Published

None to date. However, a manuscript to *Earthquake Engineering and Structural Dynamics*, is underway and will be submitted in the Fall of 2002.

Availability of Data

This project does not involve the collection of data. However, any data generated during the remainder of the project will be made available on J. van de Lindt's web page.

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